



Province of British Columbia
Ministry of Energy, Mines
and Petroleum Resources



PETROLEUM
GEOLOGY
BRANCH

COALBED METHANE IN SOUTHEAST BRITISH COLUMBIA

By David G.S. Johnson
and Leslie A. Smith

PETROLEUM GEOLOGY
SPECIAL PAPER 1991-1

91-05659/

COALBED METHANE IN SOUTHEAST BRITISH COLUMBIA

by
DAVID G. S. JOHNSON
and
LESLIE A. SMITH

SPECIAL PAPER 1991-1

for

Petroleum Geology Branch
with Support from Coal Resources Unit, Geological Survey Branch
Ministry of Energy, Mines and Petroleum Resources
Parliament Buildings, Victoria, B.C. V8V 1X4

Canadian Cataloguing in Publication Data

Johnson, David G.S.

Coalbed methane in southeast British Columbia

Includes bibliographical references: p.

ISBN 0-7718-9035-4

1. Coalbed methane - British Columbia - East Kootenay. 2. Coal - Geology - British Columbia - East Kootenay. I. Smith, Leslie A. II. British Columbia. Petroleum Geology Branch. III. Title.

TN844.7C3J63 1991 553.2'4 C91-092182-2

CONTENTS

	Page
List of Figures	ii
List of Plates	ii
List of Tables	ii
Abstract	1
Acknowledgments	1
Introduction	2
Location, Access and Infrastructure	4
Physiography	6
History of Coal Development	7
Geology	8
Regional Geology	8
Stratigraphy	8
Structure	10
Coal Characteristics	11
Coalbed Methane Resources	13
Parameters	13
Elk Valley Coalfield	14
Crowsnest Coalfield	14
Flathead Coalfield	14
Total Resources	15
Development Potential	16
Summary	16
Information Sources	17
References	18

FIGURES

	Page
1. British Columbia Coalfields	2
2. SE B.C. Coalfields and U.S. Pipeline Infrastructure	3
3. Mine Locations and Infrastructure	5
4. Stratigraphic Column	8
5. Stratigraphic Variation — SE B.C.	folded in jacket
6. Regional Coalfield Structure	folded in jacket
7. Geology of Elk Valley Coalfield	folded in jacket
8. Cross-Sections through Elk Valley Coalfield	folded in jacket
9. Geology of Crowsnest and Flathead Coalfield	folded in jacket
10. Cross-Sections through Crowsnest and Flathead Coalfield	folded in jacket
11. SE B.C. Coal Rank Distribution	folded in jacket
12. Coalbed Methane Content versus Rank and Depth	13
13. Coalbed Methane in SE B.C. based on Medium Volatile Bituminous Coal	15
14. Variation in Coalbed Methane Resource based on Coal Rank	15
15. Coalbed Methane General Inquiries	17

PLATES

1. Photograph — Elk Valley	6
2. Photograph — Flathead Ridge	6
3. Photograph — Mine Workers at Morrissey-Carbonado coalmine, circa 1905	7

TABLES

1. SE B.C. Clean Coal Production Statistics	7
2. SE B.C. Cumulative Coal Thickness Data	11
3. Elk Valley Coalfield — Coalbed Methane Content	14
4. Crowsnest Coalfield — Coalbed Methane Content	14
5. Flathead Coalfield — Coalbed Methane Content	14
6. Total Resources — Coalbed Methane	15
7. Comparison of San Juan Basin and SE B.C. Coalfields	16

ABSTRACT

The British Columbia Ministry of Energy, Mines and Petroleum Resources initiated a study of coalbed methane (CBM) in the Elk Valley, Crowsnest and Flathead coalfields of south-east British Columbia (SE B.C.). These coalfields are situated in the Front Ranges of the Rocky Mountains and have been mined since the 19th century.

The Jurassic-Cretaceous Kootenay Group contains the continental/deltaic coal-bearing sequences. The Mist Mountain Formation has the greatest CBM potential in the Kootenay Group. The Mist Mountain averages 500 metres in thickness and contains 30 to 80 metres of coal in the section. Coal rank ranges between low volatile and high volatile A bituminous. Coalfields are defined by tightly overturned to broad open folds complicated by thrust and normal or retrothrust faults. Previous geological studies have used outcrop and relatively shallow subsurface data; deeper basin control is sparse. This study extends into the subsurface and attempts to delineate and quantify the CBM resource.

Extensive research of productive CBM basins in the United States provides CBM content and production models used to quantify SE B.C. resources. The coal seams expected to contain high methane content occur at depths between 300 and 2000 metres. The volume of producible CBM gas is estimated to be 297 to 357 Gm³ (10 to 13 Tcf) in the Crowsnest coalfield and 186 to 231 Gm³ (7 to 8 Tcf) in the Elk Valley coalfield with nominal amounts in the Flathead coalfield (10 to 12 Gm³ or less than 1 Tcf) for a total of 493 to 600 Gm³ (17 to 21 Tcf). Much of this resource occurs on lands with available Petroleum and Natural Gas title.

ACKNOWLEDGMENTS

The authors thank Dave Grieve, B.C. Geological Survey Branch, for his assistance throughout the preparation of this paper and his ability to always find new data when and as required; Nick Wemyss, Energy Resources Division, B.C. MEMPR, for his support, assistance and the inspiration for the project; Neil Ollerenshaw, Institute of Sedimentary Petroleum Geology (ISPG), Calgary, for his invaluable contribution of the "Geology of the Fernie Basin", which is published for the first time in its entirety in this paper, and for his critical review of the geology; Dave Gibson, ISPG, Calgary, for providing unpublished measured sections and all staff of B.C. MEMPR who assisted us in data retrieval and report preparation and editing.

INTRODUCTION

The coalfields of southeast British Columbia are among several major coal deposits in the Province (Figure 1). Current annual production of clean coal from the five active mines in the region exceeds 18 million tonnes, most of which is coking coal sold on the export market. The other major region where coal is actively mined is northeast B.C., from which 6 million tonnes of clean coking coal is exported annually. The smaller Comox coalfield on Vancouver Island also has a planned production of up to 1 million tonnes of thermal coal per year from the Quinsam Mine (Matheson, 1989).

Coal deposits in the province vary in rank between anthracite (Groundhog coalfield in northwest B.C.) to lignite and subbituminous coal (Hat Creek deposit in southern B.C.).

Coal gas has been reported in the area since early mining activities began almost one hundred years ago. Exploitation of this energy resource has accelerated in the United States in the last decade as economic

incentives, knowledge of the reservoirs, gas source and production technology has increased. It is therefore prudent to examine the potential of similar coal deposits in B.C.

A large proportion of British Columbia's coal resources are in the Jurassic-Cretaceous Kootenay Group of southeast British Columbia (Smith, 1989). Coal resources occur in seams that can exceed 15 metres with cumulative coal thickness averaging 55 metres. Most of the coal is less than 2000 metres deep. This area has significantly greater cumulative coal thickness than the San Juan Basin in the United States. CBM resource per unit area in southeast B.C. is more than double that of the San Juan basin.

Southeast B.C. has roads, railways and towns to service the coal industry. The Alberta Natural Gas Company pipeline accesses local markets and the U.S.A., and traverses the central portion of the B.C. coalfields (Figure 2).

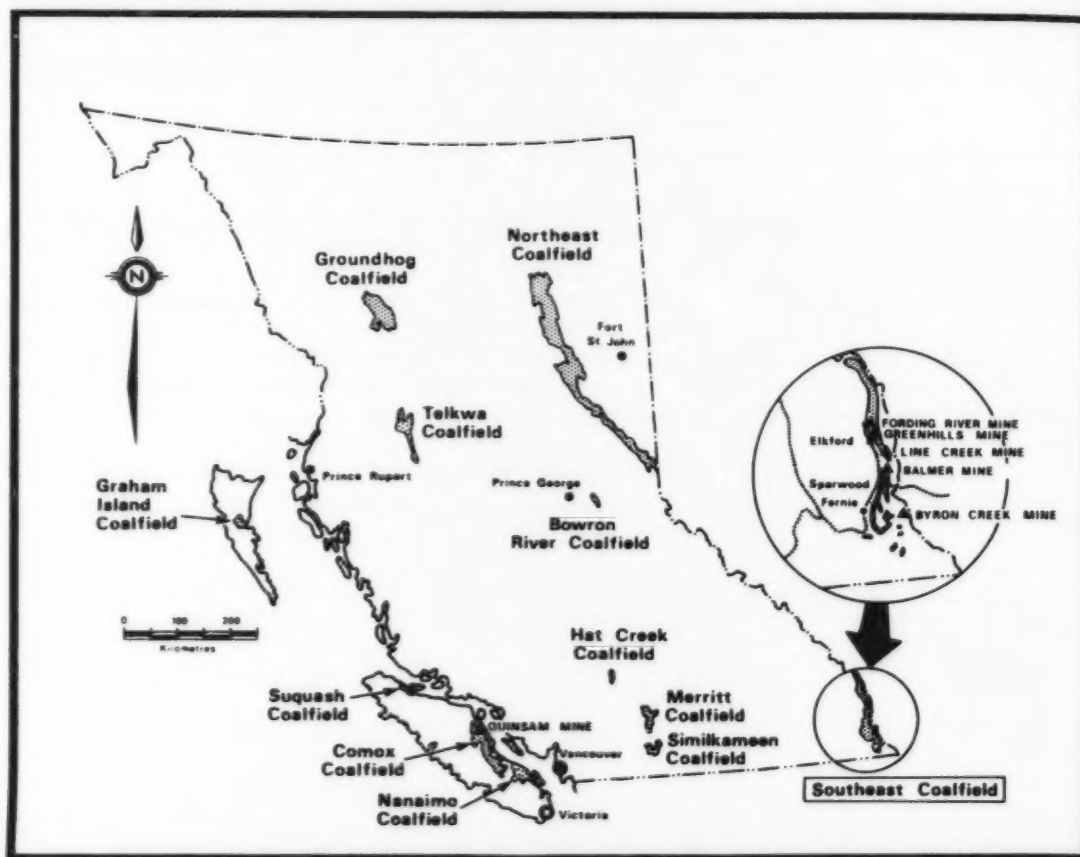


Figure 1: British Columbia Coalfields

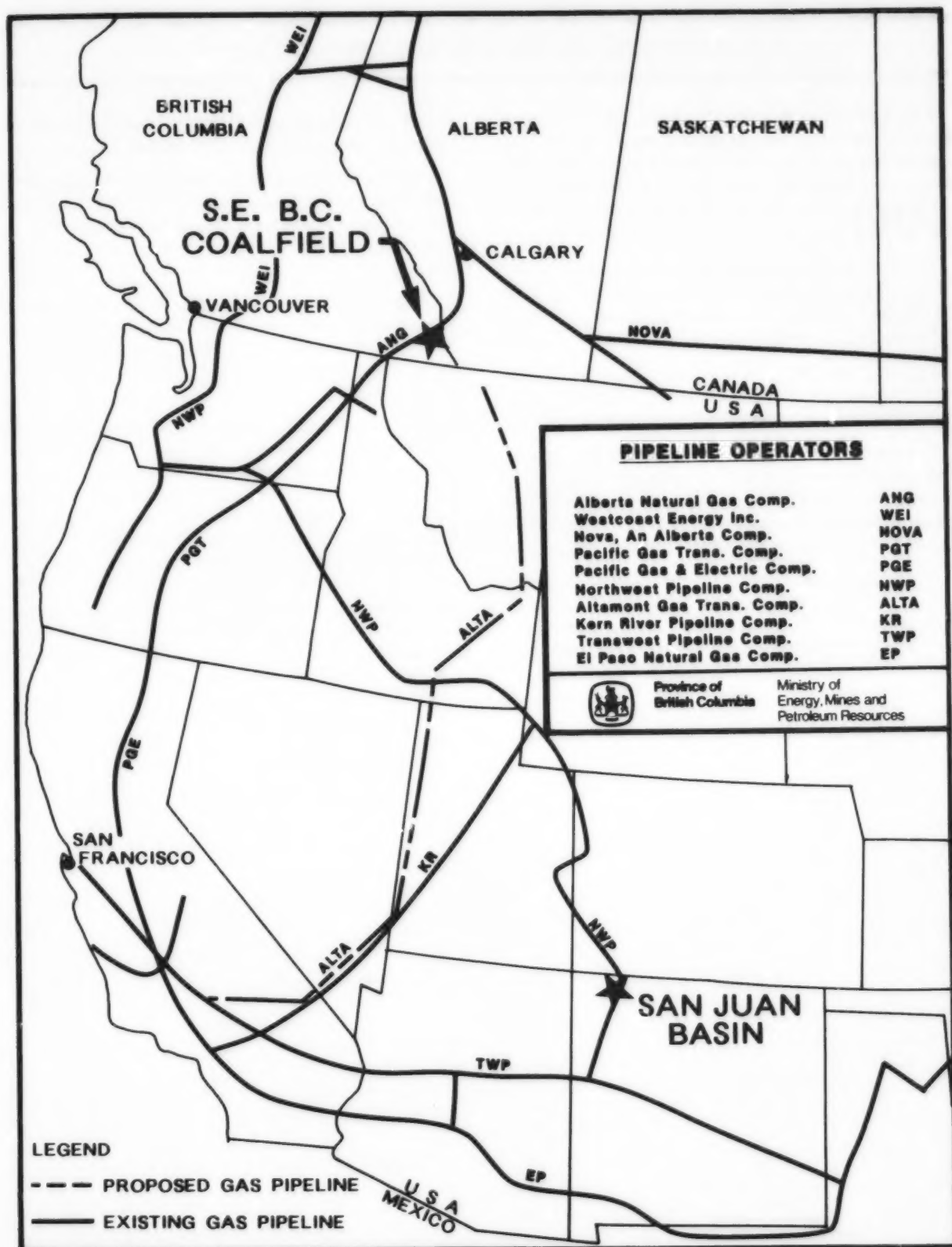


Figure 2: SE B.C. Coalfields and U.S. Pipeline Infrastructure

LOCATION, ACCESS AND INFRASTRUCTURE

The southeast British Columbia coalfields are located in the Front Ranges of the Rocky Mountains, approximately 1150 kilometres east of Vancouver. They extend in a north-south trend over 175 kilometres from the U.S. border to the Kananaskis area of Alberta, paralleling the Alberta-British Columbia border (Figure 3).

The coalfields are accessible from Highways 3 and 43 and various secondary roads. The Canadian Pacific Railway also serves the area, passing through Sparwood and Fernie, the two largest towns.

Individual coal deposits are contained in three structurally separate coalfields; the Elk Valley, Crowsnest (Fernie) and Flathead.

The Elk Valley coalfield extends across the Alberta/British Columbia border. It is 97 kilometres in length, up to 12 kilometres in width, and trends north-northwest. The southern limit of the coalfield is defined by small remnants of the coal measures on topographic highs.

Crowsnest coalfield occupies the central portion of the study area and contains the largest coal resource. The coalfield is 54 kilometres long by 24 kilometres wide. The long axis and the structures within the coalfield have

a northerly trend. Maximum depth of the coal measures in the Crowsnest coalfield is 4000 metres.

Flathead coalfield is the most southerly of the three and contains the smallest resource. The coal is preserved in scattered erosional remnants, or fault blocks. There are three main deposits; the Lillyburt, Harvey Creek and Sage Creek.

Coal is produced by Westar Mining Ltd. and Esso Resources Canada Ltd. in the Crowsnest coalfield, and by Fording Coal Ltd., Westar Mining Ltd. (Greenhills), and Crows Nest Resources Ltd. in the Elk Valley coalfield (Figure 3).

The main Alberta Natural Gas Company Limited (ANG) pipeline (36 inch) passes through the centre of the Crowsnest coalfield and connects the Alberta fields with the United States market via Kingsgate Border crossing. An 8 inch line comes off the mainline at McGillivray on Michel Creek in the Crowsnest coalfield. This line supplies the towns of Sparwood and Elkford and the operating mines in the Elk Valley (Westar's Balmer and Greenhills operations, Crows Nest's Line Creek operation and Fording Coal's Fording River mine). The pipeline reduces to 6 inches in the upper portion of the Elk River Valley.

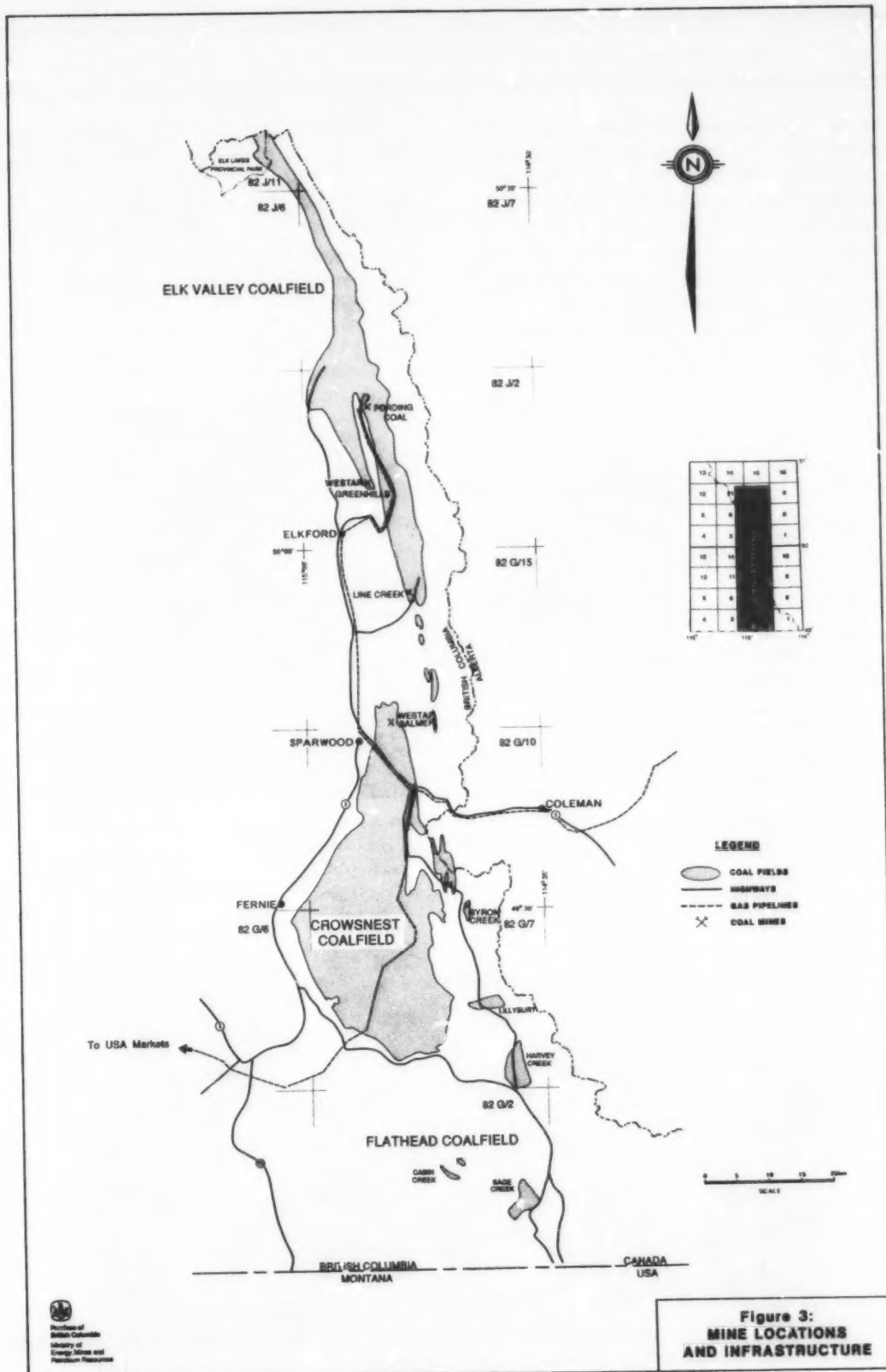


Figure 3: Mine Locations and Infrastructure

PHYSIOGRAPHY

Relief varies from the broad flat valley floors of the Elk and Flathead rivers to steep slopes flanking some ridges. The Morrissey and Elk Formations are usually well exposed. Where coal measures dip steeply into the valleys (particularly in the Elk Valley coalfield), artesian conditions may exist on the valley slopes and floor. Plateaus with varying relief exist between drainages in the central part of the Crowsnest coalfield. Plates 1 and 2 illustrate typical topographic expression in the region.

Elevations in the Elk Valley coalfield range from 1220 metres to over 2700 metres. In the Crowsnest coalfield the range is less, from 1060 metres in the Elk River valley to 2220 metres along Fernie Ridge. Average elevation of the central plateaus in the Crowsnest coalfield is 1800 to 1900 metres. Flathead coal deposits vary from 1350 metres in the Flathead valley itself to 2200 metres on the ridge tops.

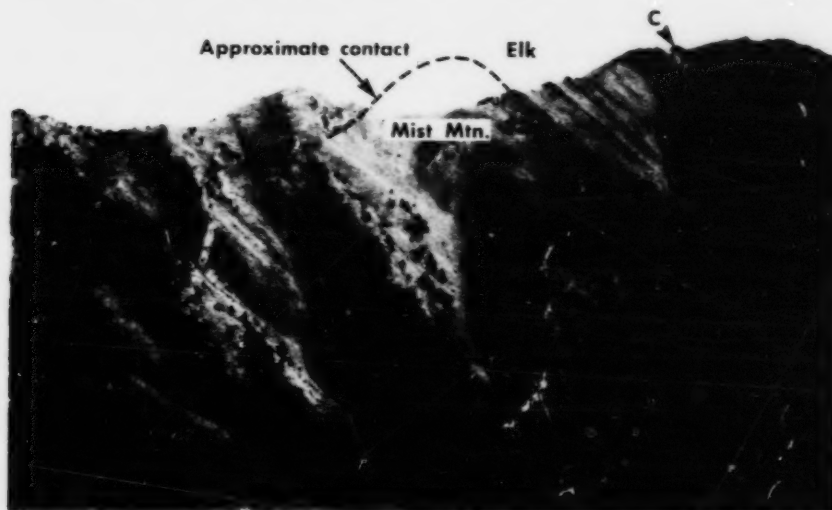


Plate 1: Kootenay Group and Cadomin Formation (c) exposed on the east limb of the Alexander Creek syncline in the Elk Valley coalfield.



Plate 2: Upper Mist Mountain Formation and Lower Elk Formation strata exposed on Flathead Ridge, south part of Crowsnest coalfield. Right-of-way for A.N.G. pipeline crosses from upper right to lower left. Note old coal exploration roads in foreground (right).

HISTORY OF COAL DEVELOPMENT IN SOUTHEAST B.C.

The historical summary is primarily from unpublished material supplied by D.A. Grieve.

Coal was first identified in 1873 by Michael Phillipps while prospecting for gold. The first geological examination in the area was conducted in 1883 by Dr. G. M. Dawson of the Geological Survey of Canada. By 1889 William Fernie, the Gold Commissioner in the region, had obtained the first coal prospecting licences for the area. Coal was extracted in late 1897 at Coal Creek near Fernie and shipped to metal mines and smelters in the Kootenay Lake area the following year. By 1901 production was about 380 000 tonnes from several collieries in the Crowsnest Coalfield. The Morrissey (Carbonado) Colliery (Plate 3), which opened in 1902, was closed by 1909, in part due to methane explosions.

Coal extraction in the region continued with annual production occasionally exceeding one million tonnes per year. Shortages of labour during wartime, changing energy requirements, alternative energy sources, and labour unrest all contributed to an unstable coal mining industry. By the late 1950s, annual production was well below one million tonnes.

The first coal sales to Japan were initiated in the 1960's. Production now exceeds 18 million tonnes per year (Table 1) from the five coal mining operations in southeast B.C.

Table 1
Southeast British Columbia
Clean Coal Production Statistics*

Mine	Production Annual Tonnage ($\times 10^6$ tonnes)	
	1989	1990
Fording River	5.8	6.3
Greenhills	3.1	3.0
Line Creek	1.9	2.1
Balmer	6.0	5.6
Byron Creek	1.6	1.5
Total	18.4	18.5

* Source: Coal Association of Canada

Underground mines at Coal Creek, Michel Creek and Morrissey Creek all experienced gas outbursts. Blowouts at Coal Creek were controlled by drilling the faces to relieve gas pressures. The contorted nature of the coal has been cited as the cause for gas and dust in some area mines. The folded nature of the strata increases permeability through fracturing. Low elevation of the mines with respect to the aquifers creates overpressuring, possibly contributing to gas outbursts at Morrissey Creek.

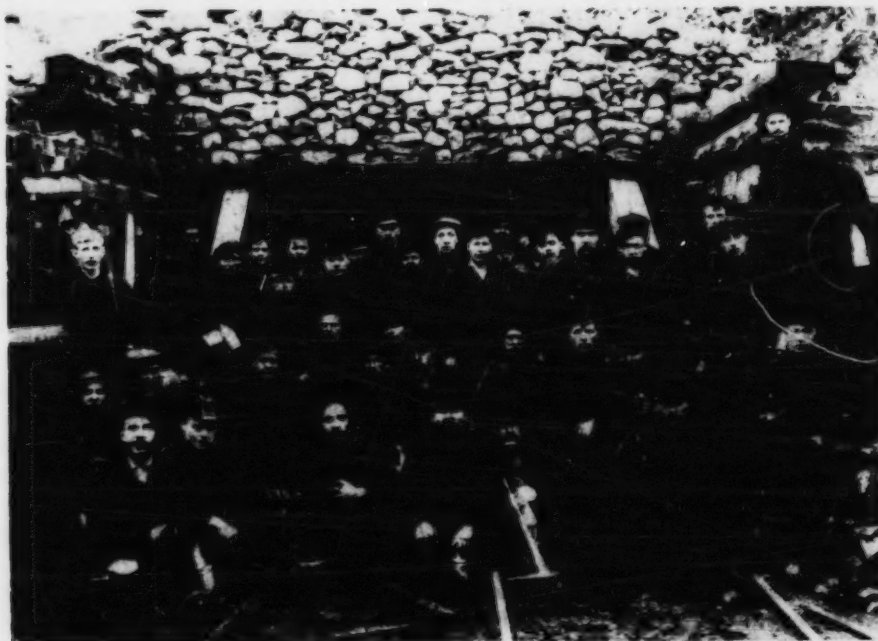


Plate 3: Mine workers at Morrissey Carbonado Coalmine, circa 1905

GEOLOGY

Regional Geology

The Jurassic-Cretaceous Kootenay Group consists of an eastward thinning wedge of predominantly non-marine, coal bearing, clastic sediments with a maximum measured thickness of 1112 metres. The group outcrops in a belt ranging from near the United States — Canada border in B.C. to the North Saskatchewan River in central Alberta, a distance of 400 kilometres. Further north, the Nikanassin Formation and Minnes Group are stratigraphic equivalents. The Kootenay Group lies conformably on the marine Fernie Formation and is overlain disconformably by the non-marine Blairmore Group. Kootenay Group rocks are absent beneath the Alberta plains because of eastward thinning resulting from pre-Blairmore erosion and distance away from the postulated western sediment source area (Gibson and Hughes 1981, Gibson 1985).

The coalfields are located within the Lewis thrust sheet. Compressional tectonics of the Late Cretaceous to Paleocene Laramide orogeny resulted in folds with north to northwest trending axes and, west-dipping thrust faults (Grieve, 1985). Extensional faulting in the late Eocene and early Oligocene (Price, 1965) resulted in some of the large normal faults recognized in the southeast B.C. coalfields.

Thick coal seams in the Kootenay Group occur in the Mist Mountain Formation which is conformable with the underlying Morrissey Formation and the overlying Elk Formation. Seams vary from less than 1 metre to greater than 15 metres in thickness and form 8 to 12 per cent of the Mist Mountain Formation (Matheson, 1986). Analyses of the coal have determined that it is relatively soft; Hard-grove Grindability Indices (HGI) range between 62 and greater than 100 (Grieve and Kilbey, 1990). Incompetent coal seams are often highly deformed. This results in many shear surfaces both oblique and parallel to layering in the coal, which in turn make the coal friable. Thickening of coal seams may occur in fold axes or as a result of closely spaced imbricate thrust faults. A seam may be the site of a detachment zone with imbricate hanging and footwall structures terminating within the seam (Gibson and Hughes, 1981).

Stratigraphy

Stratigraphic information is derived from Gibson (1985) unless otherwise indicated and the stratigraphic nomenclature is that of Gibson and Hughes (1981) (see Figure 4). The area was covered in the early Jurassic by the Fernie Sea, site of deposition of the Fernie Formation. Following uplift in the late Jurassic and early Cretaceous,

the sea retreated to the northeast. This regression is represented by sediments grading from marine (Fernie Formation) through deltaic and alluvial, (Kootenay Group), to continental (Blairmore Group).

CRETACEOUS	ALBERTA GROUP	WAPIABI FORMATION	100-m	Shale and siltstone; Marine
		CARDIUM FORMATION	50m	Sandstone and shale
		BLACKSTONE FORMATION	100m	Shale, siltstone and sandstone; Marine
	BLAIRMORE GROUP	BEAVER MINES/MILL CREEK FORMATION	1875m	Mudstone, sandstone; minor igneous and quartzite pebbles conglomerate; Non-marine
		LOWER BLAIRMORE (Gibson Formation)	455m	Mudstone, siltstone; sandstone; minor conglomerate; very minor limestone; Non-marine
		CADOMIN FORMATION	10-70m	Pebble conglomerate; sandstone; Non-marine
	KOOTENAY GROUP	ELK FORMATION	48-530m	Sandstone; siltstone; shale; thin coal; local conglomerate; Non-marine
		MIST MOUNTAIN FORMATION	120-635m	Siltstone; shale; sandstone; coal; local conglomerate; Non-marine
		MORRISSEY Fm. MOOSE MTS. HIGH RIVER, W.B.C.	30-65m	Sandstone; coarsening upward; Marine
		PASSAGE BEDS		Interbedded shale and sandstone; coarsening upward
JURASSIC	KOOTENAY GROUP	FERNIE FORMATION	250-350m	Shale; minor sandstone and limestone

Figure 4: Stratigraphic Column SE B.C.

Fernie Formation (Jurassic)

The Fernie Formation consists of marine shale, siltstone, limestone and sandstone. It is approximately 250 to 350 metres thick and unconformably overlies clastics and carbonates of the Triassic Spray River Formation. Uppermost Passage beds are a coarsening-upward sequence of interbedded shale and sandstone transitional to the Morrissey Formation of the overlying Kootenay Group (Grieve and Kilby, 1990).

Kootenay Group (Jurassic-Cretaceous)

The Kootenay Group is divided into three formations which are, in ascending order, the Morrissey, Mist Mountain and the Elk Formations.

The Morrissey Formation, at the base of the Kootenay Group, is a coarsening upward sequence of fine to coarse grained sandstones that are commonly cliff-forming. Thickness varies from 20 metres in the Sage Creek area to over 60 metres in the Elk Valley coalfield. The Morrissey Formation is divided into the Weary Ridge and Moose Mountain members. The lower Weary Ridge is a fine grained quartzose sandstone containing thin intervals of mudstone and siltstone. The upper Moose Mountain member is a quartz-chert sandstone forming a distinctive marker at the base of coal occurrences. Pebble conglomerates at Line Creek and carbonaceous layers at various locations have been recorded in the Moose Mountain member although facies changes are generally uncommon.

The Mist Mountain Formation, previously called the "Coal Bearing member", is the economically important part of the Kootenay Group (Figure 5). It is comprised of predominantly non-marine mudstones, siltstones, sandstones, and thick coal seams of bituminous rock. Thin beds of carbonaceous limestone, chert pebble conglomerates and conglomeratic sandstones have been mapped in the Crowsnest coalfield. Formation thickness varies between 122 metres at the Lillyburt deposit to 665 metres in the Greenhills Range.

Lateral facies variations in the Mist Mountain Formation make correlation between data points difficult. Strata are predominantly fine grained rocks accumulated in a flood plain. Coarse-grained sandstones are associated with river channels. Thick coal seams represent a long period of balance between peat accumulation and subsidence with little sediment input. Coals at the base of the Mist Mountain Formation were derived from coastal marsh peats. Higher up the section alluvial plain deposition is dominant.

The Non-Marine Elk Formation is the youngest Formation of the Kootenay Group. It consists of a relatively resistant succession of interbedded sandstone, siltstone, shale, mudstone, local thick conglomerate and very thin, inconsistent coal seams (Figure 5). Formation thickness varies from less than 50 metres in the Sage Creek deposit to over 600 metres in parts of the Crowsnest coalfield. Some of the thickness variation of the Elk and Mist Mountain formations may result from the difficulty in consistently defining a formation contact. The contact is defined as the base of the first major sandstone or conglomerate above the uppermost major coal seam in the Mist Mountain Formation.

The most common lithology in the Elk Formation is sandstone. Many of the thick (3 to 20 metres) units are fining upward sequences with erosional bases (Grieve and Ollerenshaw, 1989). Conglomerates are relatively rare except in the western part of the Crowsnest coalfield and extreme northern part of the Elk Valley coalfield. Conglomerates generally form the basal part of fining

upward sandstone units (Grieve and Ollerenshaw, 1989). Distinctive needle coals and siltstones, characteristic of the Elk Formation, are found in the Crowsnest and Elk Valley coalfield.

The contact with the overlying Cadomin Formation is abrupt and disconformable but may be conformable in the western limits of the study area, particularly on Fernie and Sparwood ridges.

Blairmore Group (Cretaceous)

The Blairmore Group disconformably overlies the Kootenay Group. Three units are recognized in the study area (from oldest to youngest): Cadomin Formation; lower Blairmore Group; and the Beaver Mines — Mill Creek Formation. Only the Cadomin Formation has been identified in the Elk Valley although lower Blairmore sediments may exist. In the Crowsnest coalfield a complete section of the group has been measured to the base of the Alberta Group. In the Flathead coalfield only the Cadomin Formation and lower Blairmore Group sediments are recognized.

The Cadomin Formation is a thin but laterally persistent sandstone and chert pebble conglomerate. Up to four coarse clastic units, separated by green and maroon mudstones, comprise the Cadomin in the western part of the Crowsnest coalfield where thicknesses may exceed 70 metres (Figure 5). It disconformably overlies the Kootenay Group except, as mentioned previously, in the western limits of the Crowsnest coalfield where it may be conformable. Cadomin Formation thickness is usually 10 to 30 metres and averages about 20 metres.

The Lower Blairmore Group is mapped in the Crowsnest and Flathead coalfields, and is believed to exist in the Elk Valley. This non-marine unit consists of non-carbonaceous green and maroon mudstone, siltstone, cherty sandstone and conglomerate, and limestone. Thickness is 455 metres in the Crowsnest coalfield (Ollerenshaw, 1981).

The Beaver Mines-Mill Creek Formation is the thickest unit in the Blairmore Group at 1875 metres. It consists of green and maroon mudstone, feldspathic sandstone, igneous and quartzite-pebble conglomerate. Two conglomerate bands serve as excellent markers for this formation (Ollerenshaw, 1981).

Although the Blairmore Group thins to the east, the thinning is considered to be almost entirely independent of post-Blairmore erosion (Price, 1962).

Alberta Group (Cretaceous)

The lower part of the Alberta Group occurs in the central part of the McEvoy syncline in the Crowsnest coalfield. Three formations are recognized (from oldest to youngest): Blackstone Formation; Cardium Formation; and Wapiabi Formation.

The **Blackstone Formation** consists of dark grey marine mudstone, shale, siltstone and sandstone. It is 100 metres thick within the McEvoy syncline (Ollerenshaw, 1981).

The **Cardium Formation**, which thickens from east to west, consists of sandstone and shale and attains a thickness of 50 metres in the McEvoy syncline. The formation may be non-marine within this area (Ollerenshaw, 1981).

A partial section of the **Wapiabi Formation** is present in the core of the McEvoy Syncline. This marine shale and siltstone attains a maximum thickness of 115 metres in the area (Ollerenshaw, 1981).

Structure

SE B.C. coalfields are within the Lewis thrust sheet. The three coalfields are structurally defined, being bounded by faults or outcropping on the limbs of synclines. Simplified mapping in Figure 6 illustrates the geology within the limits of the coalfields. Synclines dominate the Elk Valley and Crowsnest coalfields, with the Crowsnest referred to as a complex synclinorium (Grieve and Ollerenshaw, 1989). Structures are generally aligned north-south with some variation to the northwest-southeast (Ollerenshaw, 1981). Folding style varies from broad and open folds, to overturned folds, to tight drag folds in the footwall of thrusts.

Elk Valley Coalfield

The Alexander Creek syncline is the major structure extending throughout the 100 kilometre length of the *Elk Valley coalfield* (Figure 7, 8). It is overturned in the north central part of the basin and is open elsewhere, with a general plunge to the north (Morris and Grieve, 1988). The Greenhills syncline is the second major structure and occurs on the west side and central part of the coalfield. It is an open fold separated from the Alexander Creek syncline by the Erickson normal fault. Smaller folds are identified west of the Greenhills syncline near the Bourgeau thrust. The Bourgeau thrust forms the western limit of the north half of the Elk Basin, and is the western boundary of the Lewis thrust sheet (Morris and Grieve, 1988). The Bourgeau thrust emplaces Triassic and Jurassic sediments on the younger Kootenay Group.

Fault displacements range from the 50 kilometres of the Lewis thrust to less than a metre. Most fault planes dip southwest to west, although east-dipping, folded thrust faults do occur. Thrust faults preferentially follow incompetent coal seams and cut up-section in the competent units, resulting in stepped fault planes. Coal seams may be highly deformed because of their incompetent nature. Faulting within the seams creates many shear surfaces resulting in very friable coal and complex patterns of thickening (Gibson and Hughes, 1981).

The Erickson fault, with downthrows to 900 metres, is a major structure in southeast British Columbia. This fault separates the two major synclines and has a northern termination in the central portion of the Elk Valley coalfield.

Thrust faults affecting the coal measures are more dominant in the southern half of the Elk Valley coalfield (Morris and Grieve, 1990). Between Fording and Line Creek mines, the Ewin Pass fault repeats the Mist Mountain Formation and part of the Elk Formation. This repeat significantly increases the coal resources in the east limb of the Alexander Creek syncline. Structures associated with synclinal axes are also expected to result in thickened and faulted coal sections.

Crowsnest Coalfield

The *Crowsnest coalfield* occupies the Fernie Basin. The Fernie Basin is a complex synclinorium with the major syncline being the McEvoy syncline (Figures 9, 10). The syncline dramatically reverses plunge in the central part of the coalfield from 20° north to 25° south effectively forming a bowl. The synclines are linked en echelon by low amplitude anticlines (Price, 1962; Grieve and Kilby, 1990).

The Dominion and Lookout thrust faults, in the northern half of the coalfield, represent the compressional stages of deformation. These west-dipping faults are significant features in an imbricated fault zone interpreted by Ollerenshaw (1977) within the Dominion Coal Block, Parcel 73.

The Flathead fault is the most prominent normal fault in the Crowsnest coalfield representing the extensional phase of deformation in southeast B.C. The medium-angle Flathead fault may be a continuation of the Erickson fault in the Elk Valley coalfield (Ollerenshaw, 1981). Numerous small displacement normal faults are mapped throughout the basin.

Retrothrusting has been identified in the Crowsnest coalfield (Ollerenshaw, 1981; Pearson and Grieve, 1985). This style of faulting occurs when a reversal in slip direction on an original thrust fault is sufficient to displace the strata beyond the position of origin (Ollerenshaw, 1981). Retrothrusting is recognized on the west and east sides of the synclinorium. The east-dipping Morrissey retrothrust on the west side separates relatively undeformed strata of the Mist Mountain Formation from extremely folded and faulted strata in the footwall and is possibly a segment of one continuous Morrissey-Hinge fault. The west-dipping McEvoy fault (called "East Crop" by Grieve and others) on the east side of the coalfield is a retrothrust fault. This fault places upper Elk Formation and Lower Blairmore Group in the hanging wall over the lower Mist Mountain Formation in the footwall. Thrusting is further substantiated by the considerable deformation of Mist

Mountain Formation strata in the footwall (Ollerenshaw, 1981).

There is significant structural disturbance in the Mist Mountain Formation on the east and west sides of the basin. (Figure 9) This complex structure may be a result of:

1. faulting that bounds the coalfield — that is the Bourgeau or equivalent thrust to the west of the Elk River valley, and the Flathead normal fault to the east, or;
2. a decollement in the Mist Mountain Formation.

If the former interpretation is accepted, the coal bearing formation should be relatively undisturbed in the central part of the coalfield. However, if the latter interpretation is applied, then significant structural deformation may be anticipated in the central portion of the coalfield (Ollerenshaw, personal communication 1991). The structural characteristics of the coal measures in the central part of the basin significantly affect potential coalbed methane resources and productivity. Seam thickness (tectonic thickening), seam continuity (fault limitations), and permeability (fracturing) will be affected by structural deformation.

Flathead Coalfield

The Flathead Coalfield consists of four separate fault blocks or erosional remnants. The Lillyburt deposit, in the north, is structurally complicated and fault bounded, while the Harvey Creek, Sage Creek, and Cabin Creek deposits to the south may be considered as part of monoclines (Figures 9, 10).

The Lillyburt deposit is within the Flathead Valley graben. Movement in the graben on the north and east bounding Flathead normal fault is in the order of 1200 metres.

Detailed geologic investigations at the Sage Creek coalfield have indicated several small displacement, southwest dipping normal faults that may be related to the regional normal faults (Cullingham, 1978). The southern end of the deposit is overlain by Tertiary sediments while the northern end is cut by the Harvey fault. Deposition of the Tertiary sediments may have prevented further erosion of the underlying Kootenay Group to the south. Coal measures will be preserved beneath these sediments, extending methane potential southward.

Sage Creek and Harvey Creek coal-bearing deposits dip eastward beneath the Recent fluvial deposits of the Flathead River. Their eastern termination and ultimate depth are not known.

The Cabin Creek deposit consists of two erosional remnants of the lower Kootenay Group west of the main Sage Creek deposit. Coal in this area is less than 100

metres deep precluding any significant coalbed methane potential.

Coal Characteristics

Coal rank in southeast B.C. ranges from low to high volatile A bituminous. Rank distribution of the coals at surface is presented in Figure 11.

Coalification appears to have occurred both before and after compressional tectonics but was completed prior to extension (Pearson and Grieve, 1985; Grieve, 1991). Highest rank coals occur in the Morrissey Creek area where essentially all seams in the section are low volatile in rank. At several locations all seams are high volatile in rank (such as on the west limb of the Alexander Creeks syncline in the Weary Ridge area). Generally the base of the Mist Mountain Formation contains medium-volatile coals while the upper part contains high-volatile coals.

Petrographic data from surface exposures in the Crowsnest coalfield show that rank increases with increasing depth (Pearson and Grieve, 1985). Coal rank gradients (Pearson and Grieve, 1985) (Grieve, in press) indicate the possibility of semi-anthracite and even anthracite at depths less than 2000 metres in the Crowsnest coalfield. Gradients calculated from surface and borehole data, range up to 0.178 per cent reflectance per 100 metres (Grieve, in press). This gradient, if consistent, will result in high volatile bituminous coal becoming low volatile bituminous at less than 300 metres depth. A more representative gradient for the region would be 0.02 percent per 100 metres (Grieve, pers. comm.). In fact, data from Eagle Mountain in the Elk Valley coalfield show no downdip rank increase over a depth change of 650 metres.

Table 2
SE B.C. Cumulative Coal Thickness Data

Coalfield	Cumulative Thickness Range (in metres)	Average Cumulative Thickness (in metres)
Elk Valley	42.0–86.1 metres	59.2 metres
Crowsnest — West side	36.8–71.2 metres	55.4 metres
Crowsnest — East side	22.5–30.4 metres	27.4 metres
Flathead	17.5–28.9 metres	22.8 metres
Average of SE B.C.		55.1 metres

NOTE: A total of 32 sections were used to determine the above data; 15 from Elk Valley, 11 from Crowsnest (west), 3 from Crowsnest (east), and 3 from Flathead. The average for SE B.C. was weighted by coal resource from each area.

Coal thickness in the Mist Mountain Formation throughout southeastern B.C. is illustrated on Figure 5.

Average thicknesses used for resource evaluation are shown in Table 2.

Coal in the Mist Mountain Formation usually comprises 8 to 12 per cent of the formation thickness (Morris and Grieve, 1988; Grieve, 1985, Matheson, 1986). Mist Mountain Formation thickness averages 500 metres with 40 to 60 metres of coal measures. Thinner measured coal sections may result from excess cover obscuring the less resistant coal sections. Thicker sections may result from fault repeated seams. Gibson (1985) noted an increase in the number of seams going from south to north in south-east B.C. Individual seams also thin from south to north. Coal thickness does not vary significantly in proportion to the Mist Mountain Formation thickness. Seam thicknesses range from 28.6 metres on Morrissey Ridge (Gibson, 1985) to stringers measured in centimetres. Thickening of coal seams due to structural deformation has also been noted. The Mammoth seam at Byron Creek

collieries is reported to be up to 120 metres thick locally (Grieve, 1985).

Maceral composition varies from relatively inertinite-rich to inertinite-poor from base to top within the Mist Mountain Formation. Reactive maceral composition (ash free) ranges from less than 60 per cent in the lower seams to greater than 90 per cent in the upper seams (Grieve, 1985). This suggests that the lower coals are derived from herbaceous vegetation in contrast to the woody material (vitrinite rich) of the upper coal seams (Gibson, 1985).

The coal is relatively soft, as indicated by its high Hardgrove Grindability Indices (HGI). In the British Columbia Coal Quality Catalog (B.C. GSB Information circular 19-22, 1989) HGI varies between 62 and 135 in the Elk Valley coalfield and 62 and 112 in the Crowsnest coalfield. HGI is not recorded for the Flathead coalfield. Average HGI for Southeast B.C. is 88.

COALBED METHANE RESOURCES

Parameters

Calculations of the coalbed methane resource of SE B.C. involved the following procedure:

- Average thicknesses were calculated from measured coal thicknesses in each coalfield.
- Cross sections were constructed at approximately 5 kilometres intervals. (Some of which are illustrated in Figures 8 and 10.)
- The down-dip extent of the Mist Mountain Formation in a section was measured along the midline of the formation which may include fault — repeated coal sections.
- The section influence was modified in the Elk Valley coalfield and in the Crowsnest coalfield to remove coal excluded by current mining activities.
- Coal volumes were determined by measuring the length of the Mist Mountain Formation from cross-sections.
- The volumes of coal were measured to distinguish coals at various depths:

Shallow	< 500 metres
Average	500 to 1500 metres
Deep	1500 to 2000 metres
Too Deep	> 2000 metres

- A factor of 0.7 was used to reduce the coal volumes to account for the estimated ash content and provide the clean coal volume.

- The clean coal volume was multiplied by 1.3 tonnes per cubic metre to convert to clean coal tonnes.

Assumptions:

- Coalbed methane is directly related to the tonnage of in-place coal based on the relationship shown in Figure 12.
- This graph is the relationship established for the Fruitland Formation coals of the San Juan Basin. The San Juan Basin model is applied to Southeast B.C. CBM estimates because it is similar to the SE B.C. coalfields structurally, hydrologically (potential overpressuring) and in coal rank.
- Coals at depths of less than 500 metres were considered to have an average depth of 250 metres; 500 to 1500 metres at 1000 metres; and 1500 to 2000 metres an average of 1750 metres. CBM in coal deeper than 2000 metres was considered to be uneconomic.

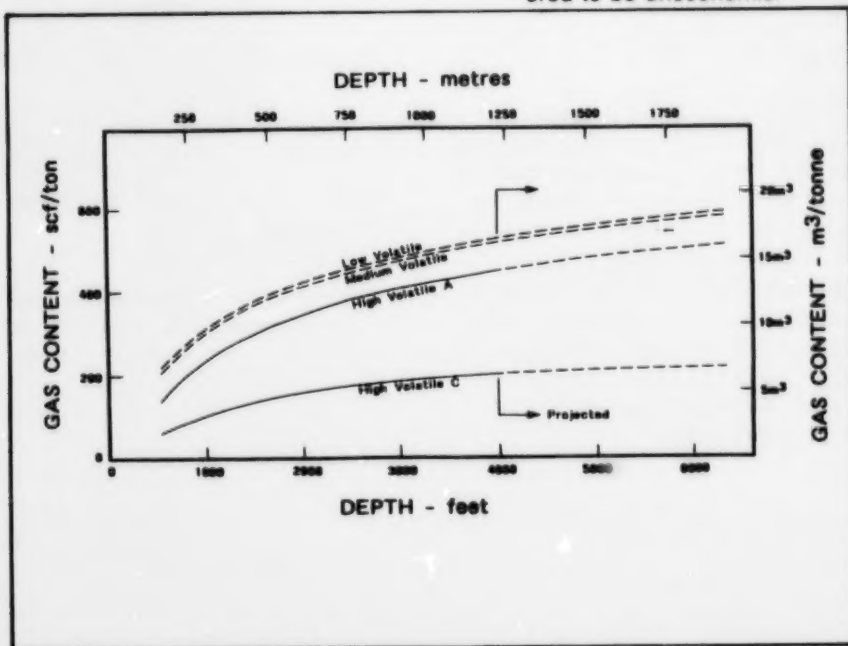


Figure 12: Coalbed Methane Content Versus Rank and Depth

- Coalbed methane content per tonne was determined using the graph in Figure 12. To convert this graph to metric values, the following factors were used:

1 Gm³ = 10⁹ m³
 1 m³ = 35.3 cf
 1 tonne = 1.1 short tons
 1 metre = 3.3 feet

- For purposes of volumetric calculations, all coals were considered to be of medium volatile bituminous rank.

Elk Valley Coalfield

All potential coal is less than 1500 metres in depth in the Elk Valley Coalfield. The CBM resource is not calculated for the small erosional remnants at the south end of the coalfield including Crown Mountain. These resources are considered too shallow to contain commercial quantities of CBM.

Table 3

Elk Valley Coalfield — Coalbed Methane Content

Depth (metres)	Clean tonnes (×10 ⁶)	Coalbed Methane Content Gm ³	Tcf
<500	9613	78	2.7
500–1500	9704	144	5.0
Total ...	19317	222	7.7

Crowsnest Coalfield

The Crowsnest Coalfield contains the largest CBM resource potential in Southeast B.C. East of the Flathead fault and McEvoy syncline, there is a significant thinning of the total coal section consistent with the overall thinning trend of the Mist Mountain Formation. Coal measure depths in the McEvoy syncline reach 4000 metres, which is too deep for current commercial CBM development.

The majority of the coalfield is in a relatively flat lying structure with coal measures between 500 and 1500 metres depth providing excellent coalbed methane potential.

Table 4

Crowsnest Coalfield — Coalbed Methane Content

Depth (metres)	Clean tonnes (×10 ⁶)	Coalbed Methane Content Gm ³	Tcf
< 500	5706	46	1.6
500–1500	18462	273	9.6
1500–2000	1462	25	0.9
>2000	2114		
Total ...	27744	344	12.1

Flathead Coalfield

Four small resource blocks in the Flathead coalfield (Lillyburt, Harvey Creek, Cabin Creek and Sage Creek) have a relatively small potential of only 400 Bcf. However, the down dip extension of both Harvey Creek and Sage Creek has not been defined beneath the Flathead River valley. These areas may contain additional coalbed methane (Figure 10). Resources were not measured for Cabin Creek because all of the coal in this erosional remnant is within 90 metres of surface.

Table 5

Flathead Coalfield — Coalbed Methane Content

Depth (metres)	Clean tonnes (×10 ⁶)	Coalbed Methane Content Gm ³	Tcf
<500	428	3	0.1
500–1500	529	8	0.3
Total ...	957	11	0.4

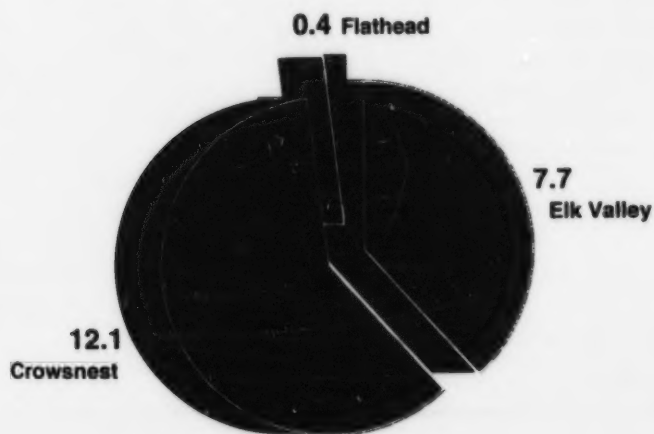
Total Resources

The potential coalbed methane resource in the Southeast B.C. coalfields is presented in Table 6. This resource volume represents 25 per cent of known conventional natural gas reserves in Canada, and 100% of B.C. initial conventional natural gas reserves. Coalbed methane represents a significant addition to B.C.'s natural gas reserves potential.

NOTE: HV = High Volatile Bituminous
MV = Medium Volatile Bituminous
LV = Low Volatile Bituminous

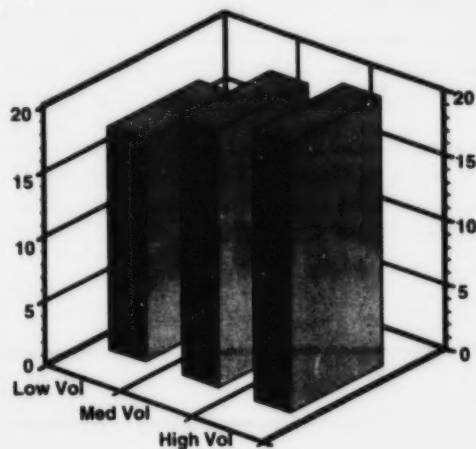
Table 6
Total Resources — Coalbed Methane

Coalfield	Clean Coal tonnes x 10 ⁶	Coalbed Methane Content (Gm ³)		
		HV	MV	LV
Elk Valley				
0- 500 m	9613	60	78	83
500-1500 m	9704	126	144	148
Crowsnest				
0- 500 m	5706	35	46	49
500-1500 m	18462	240	273	282
1500-2000 m	1462	22	25	26
+2000 m	2114			
Flathead				
0- 500 m	420	3	3	4
500-1500 m	515	7	8	8
Total	47996	493	577	600
		(17 Tcf)(20 Tcf)(21 Tcf)		



20.2 TCF in SE B.C. using Medium Volatile Bituminous Coal

Figure 13: Pie chart illustrates 20.2 TCF of coalbed methane in coalfields based on medium volatile bituminous coal



Change in Coalbed Methane Resource based on Coal Rank

Figure 14: Chart illustrates the variation in total coalbed methane resource in SE B.C. based on coal rank. Deviation in total CBM resource from medium volatile bituminous coal to low volatile or high volatile bituminous coal is approximately 10%

DEVELOPMENT POTENTIAL

The total in-situ resource of bituminous and higher rank coal in B.C. is close to 200 billion tonnes. Southeast British Columbia contains nearly a quarter of this total (Smith, 1989).

The area's population and industry have grown as a result of coal production. The 36 inch gas pipeline through the Crowsnest coalfield provides access to major natural gas markets in the U.S.A. Pipeline right-of-way and a smaller pipeline are already established, as are valuable local customers. A comprehensive geological database, including geological maps, stratigraphic studies and industry assessment reports, already exists.

The structural setting, dominated by elongate synclines, provides large uncomplicated panels of Mist Mountain Formation at attractive depths for CBM production. In conjunction with the physiographic setting, geological structure provides the opportunity to explore for local overpressured hydrologic regimes. Faulting may also provide permeable conduits for gas production. Shearing of the coal has reduced its hardness, making it suitable for cavitation completion methods which have proven highly productive in the San Juan Basin.

Numerous coal seams of varying thicknesses can be found in the Mist Mountain Formation throughout Southeast B.C., assuring a large source/host for coalbed methane. Rank of the coal is bituminous, which implies

optimum CBM storage capacity and productivity potential.

In summary, the combination of coal development, coal rank, structural style and physiography provide an ideal situation for the occurrence of very large methane resources and the potential for discovering highly productive areas.

Table 7 provides a comparison of the similarities of the Southeast B.C. coal deposits with the main producing field in the U.S.A.; the San Juan Basin.

Table 7
Comparison of San Juan Basin
and SE B.C. Coalfields

Parameter	SE B.C.	San Juan
Structure	Faulted Synclines	Asymmetric Synclinerium
Avg. Depth (m)	900 m	1000 m
Avg. Coal Thick (m) . . .	55 m	18 m
Max. Coal Rank	LV	LV
Min. Coal Rank	HV	Sub bit.
Resources	20 Tcf	50 Tcf
Max. Gas in Place (Potential)	75 Bcf/Section	35 Bcf/Section
Prime Area	8 Twps	30 Twps

SUMMARY

- Excellent CBM potential exists in the Southeast B.C. coalfields.

Elk Valley	up to 231 Gm ³	(8 Tcf)
Crowsnest	up to 357 Gm ³	(12.4 Tcf)
Flathead	up to 12 Gm ³	(<1 Tcf)
Total	up to 600 Gm³	(21 Tcf)

- Infrastructure access is in place to access the resource including a large 36 inch gas pipeline tied to markets in the U.S.A.

- Provision exists in the Petroleum and Natural Gas Act for test hole drilling. This may assist in the evaluation of CBM potential without requiring P&NG title.
- Coal thickness and rank provide an ideal source and host rock for coalbed methane.
- Physiography and structure provide opportunities for overpressuring and enhanced permeability zones.
- Large tracts of land are currently available for P&NG land acquisition in these areas.

INFORMATION SOURCES

The coal measures in the study area straddle the B.C./Alberta provincial border. Studies of the area have been conducted by a variety of agencies. The following list identifies those which may provide further information on coal or coalbed methane resources.

1. British Columbia Ministry of Energy, Mines and Petroleum Resources
Energy Resources Division and Mineral Resources Division
437 — 617 Government Street
Victoria, British Columbia
Phone: (604) 356-2743
2. The Institute of Sedimentary and Petroleum Geology
(Geological Survey of Canada)
3303 — 33rd Street N.W.
Calgary, Alberta T2L 2A7
ISPG Publications: Phone: (403) 292-7030
3. CANMET (Energy, Mines and Resources Canada)
One Oil Patch Drive
Devon, Alberta T0C 1E0
Phone: (403) 987-8215
4. The Coal Association of Canada
502, 205 — 9th Ave S.E.
Calgary, Alberta T2G 0R3
Phone: (403) 262-1544

The British Columbia Ministry of Energy, Mines and Petroleum Resources (MEMPR) manages and regulates petroleum, natural gas, coal and minerals resources within the province. The Ministry's responsibilities include land tenure, resource evaluation studies, data acquisition and compilation, and approval and regulation of resource development. The Ministry maintains numerous records, including work performed in prospect areas and publications available to the general public.

The Ministry is divided into two divisions. The Energy Resources Division is responsible for Petroleum and Natural Gas (P&NG) including land titles, well data, drilling and public domain data. In the Mineral Resources Division, the Coal Resources Unit of the Geological Survey Branch can provide access to coal geology data, assessment reports and COALFILE.

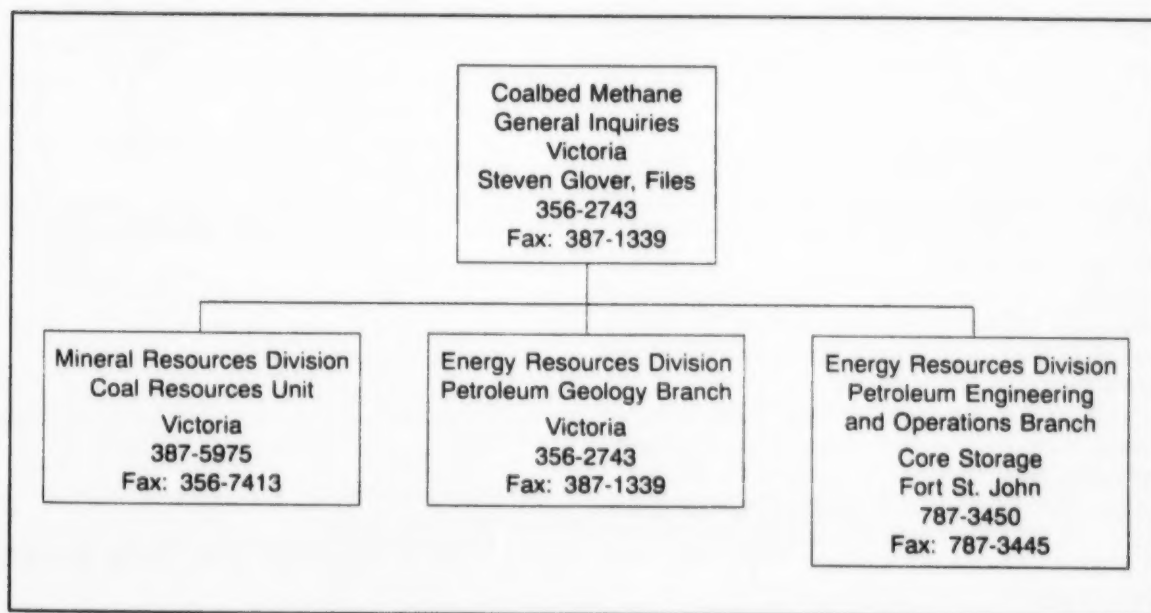


Figure 15: Coalbed Methane Inquiries, B.C. Ministry of Energy, Mines and Petroleum Resources

REFERENCES

- British Columbia Geological Survey Branch, (1989): British Columbia Coal Quality Catalog; B.C. Ministry of Energy, Mines and Petroleum Resources, Information Circular 1989-22.
- Bustin, R.M., (1979): Characteristics and Mechanism for the Formation of Structurally Thickened Coal Deposits in the Southeastern Canadian Cordillera; Ninth International Congress of Carboniferous Stratigraphy and Geology, Program with Abstracts, pages 27-28.
- Bustin, R.M., (1981): Preliminary Investigations as to the Effects of Shear on Coal Quality in Southeastern British Columbia; B.C. Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork 1980, pages 133-148.
- Crowsnest Resources Limited, (1978): Open File Assessment Report #401, Shell-Harvey Ck.; Unpublished Company Report.
- Cullingham, O. (1978): Report on Field Investigations, September-November 1977, Open File Assessment Report #372, B.C. Ministry of Energy, Mines and Petroleum Resources, Sage Creek Coal Ltd.
- Elco Mining Ltd., (1978): Assessment Report #276, Unpublished Company Report.
- Gibson, D.W. and Hughes, J.D., (1981): Structure, stratigraphy, sedimentary environments and coal deposits of the Jura-Cretaceous Kootenay-Group, Crowsnest Pass area, Alberta and British Columbia; Field Guides to Geology and Mineral Deposits, Geological Association of Canada Annual Meeting, Calgary, 39 pages.
- Gibson, D.W., (1985): Stratigraphy, Sedimentology and Depositional Environments of the Coal-bearing Jurassic-Cretaceous Kootenay Group, Alberta and British Columbia, Geological Survey of Canada, Bulletin 357, 108 pages.
- Gigliotti, F.B. and Pearson, D.E., (1978): Preliminary Geological Map of Crowsnest Coalfield, Northeast Part, B.C. Ministry of Energy, Mines and Petroleum Resources, Preliminary Map 31.
- Grieve, D.A., (1981): Flathead Coalfield; B.C. Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork 1980, Paper 1981-1, pages 64-69.
- Grieve, D.A. and Pearson, D.E., (1983): Geology of the Greenhills Range Elk Valley Coalfield; B.C. Ministry of Energy, Mines and Petroleum Resources, Preliminary Map 51.
- Grieve, D.A., (1985): Coalfields of the East Kootenay Region, southeastern British Columbia; in T. Pechung, Editor, Coal in Canada, Cdn. Inst. Min & Metallurgy Special volume 31, pages 203-211.
- Grieve, D.A. and Fraser, J.M., (1985): Geology of the Elk Valley Coalfield, Southern Half (Kilmarnock Creek to Alexander Creek); B.C. Ministry of Energy, Mines and Petroleum Resources, Preliminary Map 60.
- Grieve, D.A. and Price, R.A., (1985): Geological Setting of the South Half of the Elk Valley Coalfield Southeastern British Columbia (Part of 82G/15 and 82J/2), B.C. Ministry of Energy, Mines and Petroleum Resources, Preliminary Map 63.
- Grieve, D.A., (1987): Coal Rank Distribution, Flathead Coalfield, Southeastern B.C. (82G/2, 82G/7); B.C. Ministry of Energy, Mines and Petroleum Resources Geological Fieldwork, 1986, Paper 1987-1, pages 361-364.
- Grieve, D.A. and Ollerenshaw, N.C., (1989): Stratigraphy of the Elk Formation in the Fernie Basin, Southeastern British Columbia; B.C. MEMPR, Paper 1989-2, 79 pages.
- Grieve, D.A., (1990): British Columbia Coal Specifications; B.C. MEMPR Information Circular 1990-5.
- Grieve, D.A. and Kilby, W.E., (1990): Geology and Coal Resources of the Dominion Coal Block, southeastern British Columbia; B.C. Ministry of Energy, Mines and Petroleum Resources, Paper 1989-4, 49 pages.
- Grieve, D.A., (in press): Biaxial Vitrinite Reflectance in Coals of the Elk Valley Coalfield, Southeastern British Columbia, International Journal of Coal Geology.
- Grieve, D.A., (in prep): Geology and Rank Distribution of the Elk Valley Coalfield Southeastern British Columbia, B.C. Ministry of Energy, Mines and Petroleum Resources Bulletin 68.
- Kaiser Resources, (1974): Correlation Chart, Elk Member, Fernie Ridge-Martin Ridge-Sparwood Ridge; Company Report.
- MacKenzie, J.D., (1916): Geology of a portion of the Flathead coal area, British Columbia, Geological Survey of Canada, Memoir 87, 53 pages.
- Matheson, A., (1986): Coal in British Columbia, British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1986-3, 170 pages.
- Matheson, A., (1989): Producing and Developing Thermal Coal Properties in British Columbia, British Columbia Ministry of Energy, Mines and Petroleum Resources Open File 1988-23, 36 pages.
- Morris, R.J. and Grieve, D.A., (1988): Geology of the Elk Valley Coalfield North Half Henretta Creek to Elk Lakes; B.C. Ministry of Energy, Mines and Petroleum Resources, Preliminary Map 68.

- Ollerenshaw, N.C., (1977): Canadian Government Coal Block, Parcel 73, Fernie Basin, British Columbia, in Current Research, Part A, Geological Survey of Canada, Paper 81-1A, pages 155-159.
- Ollerenshaw, N.C., Pearson, D.E., Gigliotti, F. and Grieve, D.A., (1977): Geology of Crowsnest Coalfield, Northwest Part; B.C. Ministry of Energy, Mines and Petroleum Resources, Preliminary Map 24.
- Ollerenshaw, N.C., (1981): Parcel 82, Dominion Coal Block, Southeastern British Columbia; in Current Research, Part B; Geological Survey of Canada Paper 81-1B, pages 145-152.
- Pearson, D.E., Gigliotti, F. and Grieve, D.A., (1977): Geology of Crowsnest Coalfield Northwest Part; B.C. Ministry of Energy, Mines and Petroleum Resources, Preliminary Map 24.
- Pearson, D.E. and Grieve, D.A., (1978): Geology of Crowsnest Coalfield West Part; B.C. Ministry of Energy, Mines and Petroleum Resources, Preliminary Map 27.
- Pearson, D.E. and Grieve, D.A., (1981): Geology of Crowsnest coalfield, southern part; B.C. Ministry of Energy, Mines and Petroleum Resources, Preliminary Map 42.
- Pearson, D.E. and Grieve, D.A., (1985): Rank Variation, Coalification Pattern and Coal Quality in the Crowsnest Coalfield, British Columbia; Canadian Institute of Mining, Bulletin, Volume 78, pages 39-46.
- Price, R.A., (1962): Fernie Map-area, East Half, Alberta and British Columbia, 82G/E 1/2; Geological Survey of Canada, Paper 61-24, 65 pages.
- Price, R.A., (1965): Flathead Map-area, British Columbia and Alberta; Geological Survey of Canada, Memoir 336, 221 pages.
- Rankin, A., (1991): Gas Prices Gaining Ground on Oil, Oilweek, January 21, 1991, Vol. 41, No. 49, pages 10-16.
- Smith, G.G., (1989): Coal Resources of Canada, Geological Survey of Canada Paper 89-4, 146 pages.